NASA Electronic Parts and Packaging (NEPP) Program Plans

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Sundown at SCRIPPS Proton Therapy Center, Ken LaBel

To be presented by Kenneth A. LaBel at the Radiation Hardened Electronics Technology (RHET) Conference, San Antonio, TX, October 25-26, 2016. Plus TowerJazz Technical Global Symposium (TGS) Aerospace & Defense Day (A&D) Day, October 27, 2016.

Acronyms

Acronym	Definition
1MB	1 Megabit
3D	Three Dimensional
3DIC	Three Dimensional Integrated Circuits
ACE	Absolute Contacting Encoder
ADC	Analog to Digital Converter
AEC	Automotive Electronics Council
AES	Advanced Encryption Standard
AF	Air Force
AFRL	Air Force Research Laboratory
AFSMC	Air Force Space and Missile Systems Center
AMS	Agile Mixed Signal
ARM	ARM Holdings Public Limited Company
BGA	Ball Grid Array
BOK	Body of Knowledge
CAN	Controller Area Network
CBRAM	Conductive Bridging Random Access Memory
CCI	Correct Coding Initiative
CGA	Column Grid Array
CMOS	Complementary Metal Oxide Semiconductor
CN	Xilinx ceramic flip-chip (CF and CN) packages are ceramic column grid array (CCGA) packages
COTS	Commercial Off The Shelf
CRC	Cyclic Redundancy Check
CRÈME	Cosmic Ray Effects on Micro Electronics
CRÈME MC	Cosmic Ray Effects on Micro Electronics Monte Carlo
CSE	Crypto Security Engin
CU	Control Unit
D-Cache	defered cache
DCU	Distributed Control Unit
DDR	Double Data Rate (DDR3 = Generation 3; DDR4 = Generation 4)
DLA	Defense Logistics Agency
DMA	Direct Memory Access
DMEA	Defense MicroElectronics Activity
DoD	Department of Defense
DOE	Department of Energy
DSP	Digital Signal Processing
dSPI	Dynamic Signal Processing Instrument
Dual Ch.	Dual Channel
ECC	Error-Correcting Code
EEE	Electrical, Electronic, and Electromechanical
EMAC	Equipment Monitor And Control
EMIB	Multi-die Interconnect Bridge
ESA	European Space Agency
eTimers	Event Timers
ETW	Electronics Technology Workshop
FCCU	Fluidized Catalytic Cracking Unit
FeRAM	Ferroelectric Random Access Memory
FinFET	Fin Field Effect Transistor (the conducting channel is wrapped by a thin silicon "fin")
FPGA	Field Programmable Gate Array
FPU	Floating Point Unit
FY	Fiscal Year
GaN	Gallium Nitride
GAN GIT	Panasonic GaN GIT Eng Prototype Sample
GAN SIT	Gallium Nitride GIT Eng Prototype Sample
Gb	Gigabyte
GCR	Galactic Cosmic Ray
GIC	Global Industry Classification

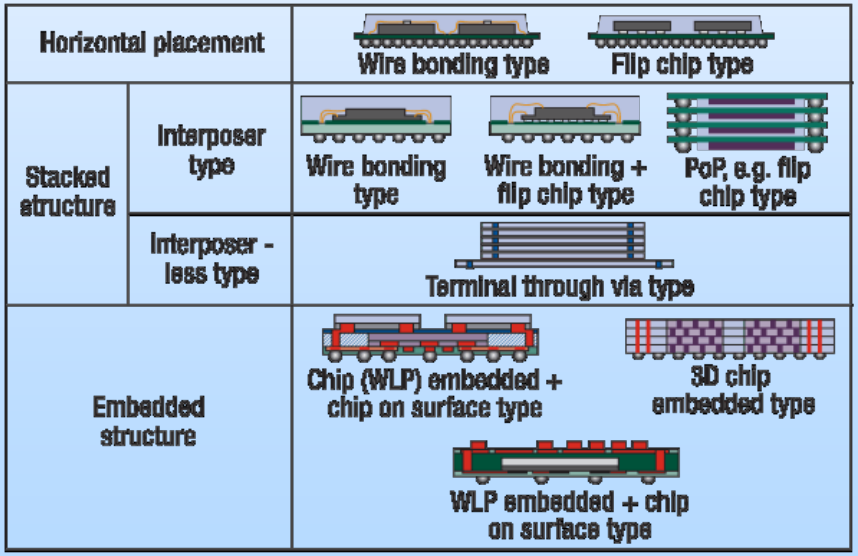
Acronym	Definition
Gov't	Government
GPU	Graphics Processing Unit
GRC	NASA Glenn Research Center
GSFC	Goddard Space Flight Center
GSN	Goal Structured Notation
GTH/GTY	Transceiver Type
HALT	Highly Accelerated Life Test
HAST	Highly Accelerated Stress Test
HBM	High Bandwidth Memory
HDIO	High Density Digital Input/Output
HDR	High-Dynamic-Range
HiREV	High Reliability Virtual Electronics Center
HMC	Hybrid Memory Cube
HP Labs	Hewlett-Packard Laboratories
HPIO	High Performance Input/Output
HPS	High Pressure Sodium
HUPTI	Hampton University Proton Therapy Institute
I/F	interface
I/O	input/output
I2C	Inter-Integrated Circuit
i2MOS	Microsemi second generation of Rad-Hard MOSFET
IC	Integrated Circuit
IC	Integrated Circuit
I-Cache	independent cache
IUCF	Indiana University Cyclotron Facility
JFAC	Joint Federated Assurance Center
JPEG	Joint Photographic Experts Group
JTAG	Joint Test Action Group (FPGAs use JTAG to provide access to their programming debug/emulation functions)
KB	Kilobyte
L2 Cache	independent caches organized as a hierarchy (L1, L2, etc.)
LANL	Los Alamos National Laboratories
LANSCE	Los Alamos Neutron Science Center
LLUMC	Loma Linda University Medical Center
L-mem	Long-Memory
LP	Low Power
LVDS	Low-Voltage Differential Signaling
LW HPS	Lightwatt High Pressure Sodium
M/L BIST	Memory/Logic Built-In Self-Test
MBMA	Model-Based Missions Assurance
MGH	Massachusetts General Hospital
Mil/Aero	Military/Aerospace
MIPI	Mobile Industry Processor Interface
MMC	MultiMediaCard
MOSFET	Metal-Oxide-Semiconductor Field-Effect Transistor
MP	Microprocessor
MP	Multiport
MPFE	Multiport Front-End
MPU	Microprocessor Unit
Msg	message
NAND	Negated AND or NOT AND
NASA	National Aeronautics and Space Administration
NASA STMD	NASA's Space Technology Mission Directorate
Navy Crane	Naval Surface Warfare Center, Crane, Indiana
NEPP	NASA Electronic Parts and Packaging
NGSP	Next Generation Space Processor
NOR	Not OR logic gate

Acronym	Definition
NRL	Naval Research Laboratory
NRO	United States Navy National Reconnaissance Office
NSWC Crane	Naval Surface Warfare Center, Crane Division
OCM	On-chip RAM
PBGA	Plastic Ball Grid Array
PC	Personal Computer
PCB	Printed Circuit Board
PCIe	Peripheral Component Interconnect Express
PCIe Gen2	Peripheral Component Interconnect Express Generation 2
PLL	Phase Locked Loop
POL	point of load
PoP	Package on Package
PPAP	Production Part Approval Process
Proc.	Processing
PS-GTR	High Speed Bus Interface
QDR	quad data rate
QFN	Quad Flat Pack No Lead
QSPI	Serial Quad Input/Output
R&D	Research and Development
R&M	Reliability and Maintainability
RAM	Random Access Memory
ReRAM	Resistive Random Access Memory
RGB	Red, Green, and Blue
RH	Radiation Hardened
SATA	Serial Advanced Technology Attachment
SCU	Secondary Control Unit
SD	Secure Digital
SD/eMMC	Secure Digital embedded MultiMediaCard
SD-HC	Secure Digital High Capacity
SDM	Spatial-Division-Multiplexing
SEE	Single Event Effect
SESI	secondary electrospray ionization
Si	Silicon
SiC	Silicon Carbide
SK Hynix	SK Hynix Semiconductor Company
SLU	Saint Louis University
SMDs	Selected Item Descriptions
SMMU	System Memory Management Unit
SNL	Sandia National Laboratories
SOA	Safe Operating Area
SOC	Systems on a Chip
SPI	Serial Peripheral Interface
STT	Spin Transfer Torque
TBD	To Be Determined
Temp	Temperature
THD+N	Total Harmonic Distortion Plus Noise
TRIUMF	Tri-University Meson Facility
T-Sensor	Temperature-Sensor
TSMC	Taiwan Semiconductor Manufacturing Company
U MD	University of Maryland
UART	Universal Asynchronous Receiver/Transmitter
UFHPTI	University of Florida Proton Health Therapy Institute
UltraRAM	Ultra Random Access Memory
USB	Universal Serial Bus
VNAND	Vertical NAND
WDT	Watchdog Timer

Outline

- NEPP Frame of Reference and Overview
- NEPP Tasks and Technology Selection
  - NEPP Technology Criteria
  - Selective Task “Roadmaps” including COTS
- Protons and Pictures
- Summary

Advanced 3D packaging provides challenges for radiation and reliability testing



http://electroiq.com/blog/2010/08/achieving-cost-and/

NEPP - Frame of Reference

- **EEE (electrical, electronic, and electromechanical) parts are:**
  - **All the things that are on printed circuit boards (PCB) inside of electronics boxes.**
- **This includes:**
  - **Integrated Circuits (ICs or chips) like processors and memories as well as passives such as capacitors and resistors,**
  - **Hybrid devices or multi-chip modules: Small packages that house multiple chips internally that are placed on the PCB, and,**
  - **Connectors and wires used to send electrical or power signals between boards, boxes, or systems.**
- **This does not include:**
  - **The PCB - NASA Workmanship Program responsibility.**

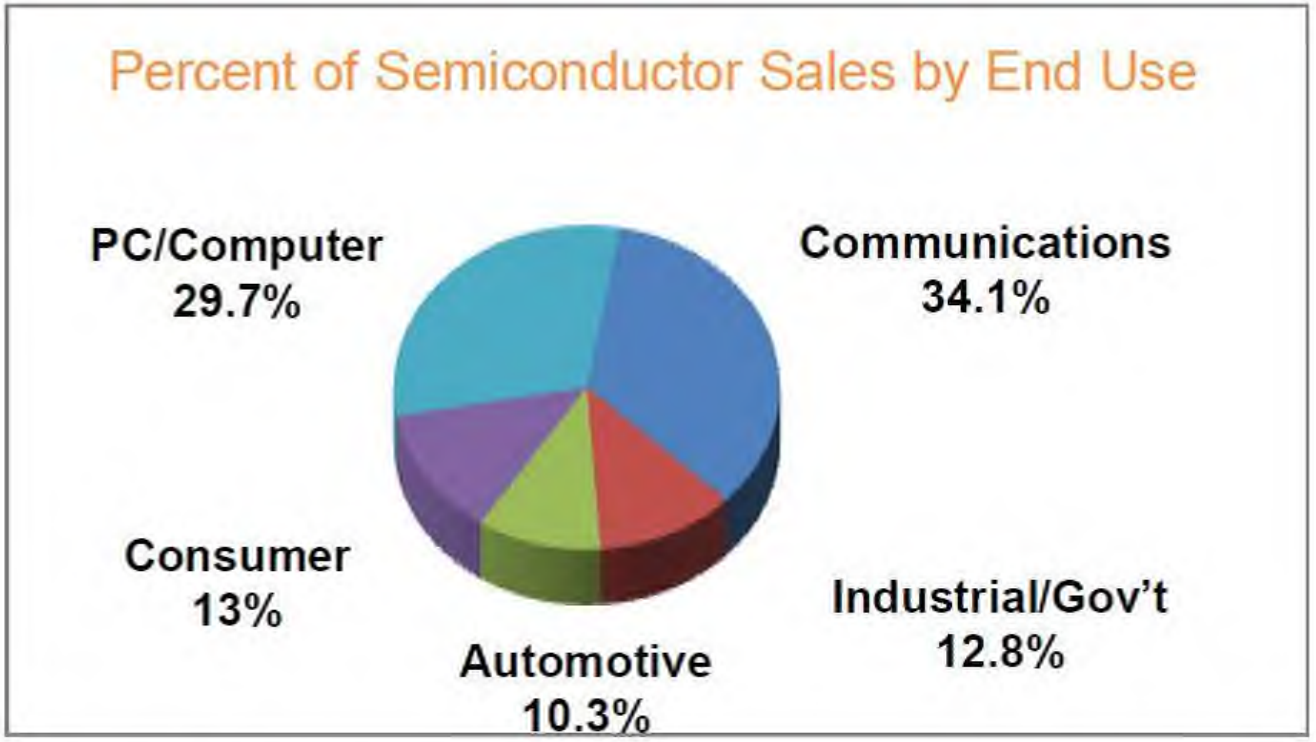
PCB from Mars Rover
Image courtesy NASA

Image courtesy BAE Systems

Image courtesy NASA

Motivational Factors

2015 Global Semiconductor Market: $335 Billion



Source: WSTS End Use Report, 2015
Note: Military is <1% and is included in Industrial/Gov't

Military and Aerospace share is estimated at ~$3.1B in 2015.

Aerospace is a small percentage of this amount.

For comparison, in 1975

the Military and Aerospace market share was ~$50%!

Conclusion: Mil/Aero community has to leverage other industries

What NEPP Does

- **Supports the assurance infrastructure by**
  - **Ensuring NASA interests are included in Military, Aerospace, and Industry Standards,**
  - **Providing forums for aerospace community interchange and collaboration, and,**
  - **Maintaining Agency EEE parts standards and policy.**
- **NEPP develops guidance on EEE parts technologies by delivery of**
  - **Body of Knowledge (BOK) documents**
    - **See next chart**
  - **Guideline documents, and,**
  - **Technical reports and papers.**
- **Annual Electronics Technology Workshop (ETW)**
  - **2017 version will be on June 19-22**

BOK Documents

- **What goes into a BOK**
  - **An overview of the technology**
  - **An overview of technology applicability to space/aeronautics**
  - **An overview of technology maturity, produceability and/or commercial availability**
  - **Reliability, qualification, and/or radiation knowledge-base**
  - **Technology direction or extent of the reliability issue for the future Identification of experts, technology sources, test houses, etc.**
  - **Facilities/capabilities**
  - **Recommendation for follow-on NEPP task (if applicable)**
- **Examples of BOKs**
  - **Recently released**
    - **Copper Wirebonds (now in update), SiC, Integrated Photonics**
  - **Already in development**
    - **Automotive Electronics, Graphics Processing Units (GPUs), 3D Integrated Circuits (3DICs), Fiber Optics**
  - **New starts: Mil-Aero product updates**
    - **DC-DC**
    - **Converters, Point of Load (POL) Converters, Analog to Digital Converters (ADCs)**

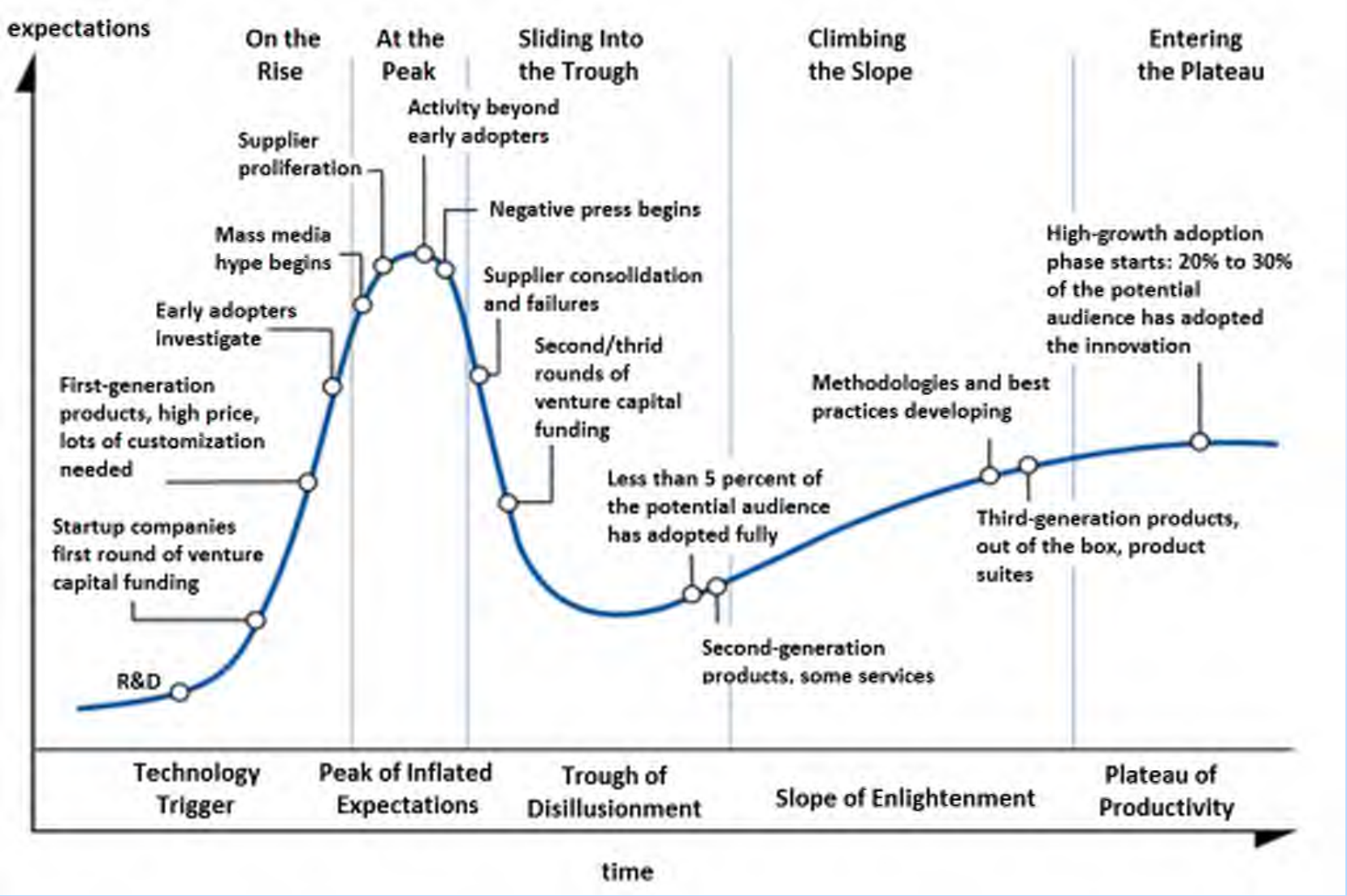
NEPP – Deeper Dive for Tasks

- **NEPP has multiple rationale for evaluating a specific device or technology:**
  - **If the device/technology has the potential for widespread usage across the Agency,**
  - **If the device has true enabling characteristics for next generation mission needs, or,**
  - **As a means of gathering assurance information for future mission insertion or screening/qualification methods.**
- **Technologies must be "on a path to commercialization" (i.e., planned industry product)**
- **Partnering with other Agencies, industry, and universities is encouraged**
- **The following roadmap charts are focused on the advanced power and digital electronics regimes as well as "small missions".**

NEPP Agency Collaborations

Topic	Agency(ies)	Description
3-D Integrated Circuits (ICs)	AFSMC, DMEA, AFRL, NRO, Missile Defense Agency (MDA), Navy Crane	Working Group to explore future assurance for commercial and military 3D (ICs).
Advanced processors and Systems on a Chip (SOCs)	Navy Crane	Radiation evaluation of advanced technology microprocessors and SOCs..
Advanced Non-Volatile Memories	Navy Crane	Radiation and reliability evaluation of advanced technology, non-volatile memories
Audits, Manufacturer and Test Houses	Defense Logistics Agency (DLA), Air Force Space & Missile Systems Center (AFSMC)	Joint audits of EEE parts manufacturers and test houses relevant to NASA needs
Automotive Electronics	Navy Crane, AFSMC	Evaluation of reliability of automotive electronics for space considerations.
FPGAs- Microsemi	AFSMC	Independent radiation testing of new radiation tolerant FPGA from Microsemi.
FPGAs - Xilinx	Sandia National Laboratories (SNL), Los Alamos National Laboratories (LANL)	Team for independent radiation evaluation of next generation Xilinx "space product" FPGA
Military Electronics Qualification Review	Defense Logistics Agency (DLA), Air Force Space & Missile Systems Center (AFSMC)	Review of proposed changes to MIL specs and standards as well as (SMDs), etc...
NEPP Radiation Testing	AFSMC	Cooperative effort with Air Force SMC
Proton Radiation Test Facilities	AFSMC, National Reconnaissance Office (NRO)	Team evaluation of options for proton testing now Indiana University Cyclotron Facility (IUCF) is closed
Radiation Test Facility Infrastructure Study	AFSMC, DOE	Study by National Academies of Science to review aging test facility etc.
Trusted Foundry and Trusted FPGAs	AFSMC, DMEA, AFRL, NRO, Missile Defense Agency (MDA), Navy Crane, Joint Federated Assurance Center (JFAC)	Supporting DoD studies on the future for trusted electronics and foundry access.
Trusted FPGA	AFSMC, DMEA, AFRL, NRO, Missile MDA, Navy Crane, JFAC	Supporting DoD funded effort for development of new trusted product.
Widebandgap Working Group	High Reliability Virtual Electronics Center (HiREV) - AFRL DMEA; NRL	Coordinated efforts in radiation and reliability work on both GaN and SiC widebandgap technology devices.

Diatribe: Gartner Hype Cycle Concept



Field Programmable Gate Arrays (FPGAs)

New "Space" FPGAs from the "Agencies"

- **DoD-led Trusted FPGA**
- **ESA "BRAVE" FPGA**

TBD – (track status)

Altera

- **Stratix 5 (28nm TSMC process commercial)**
- **Max 10 (55nm NOR based commercial – small mission candidate)**
- **Stratix 10 (14nm commercial - TriGate)**

Radiation Testing

Radiation Testing ***Reliability Testing***

Radiation Testing

Microsemi

- **RTG4 (65nm RH)**

Radiation Testing

Package Reliability Testing

Xilinx

- **7 series (28nm commercial)**
- **Ultrascale (20nm commercial – planar)**
- **Ultrascale+ (16nm commercial - vertical)**
- **Virtex 5QV (65nm RH)**

Radiation Testing

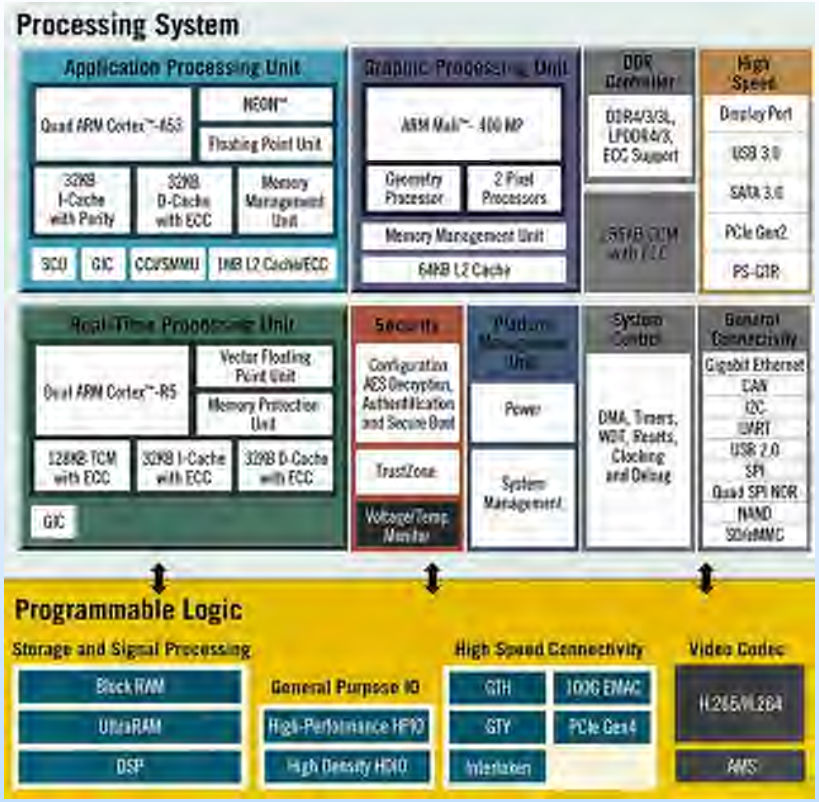
Radiation Testing

Radiation Testing

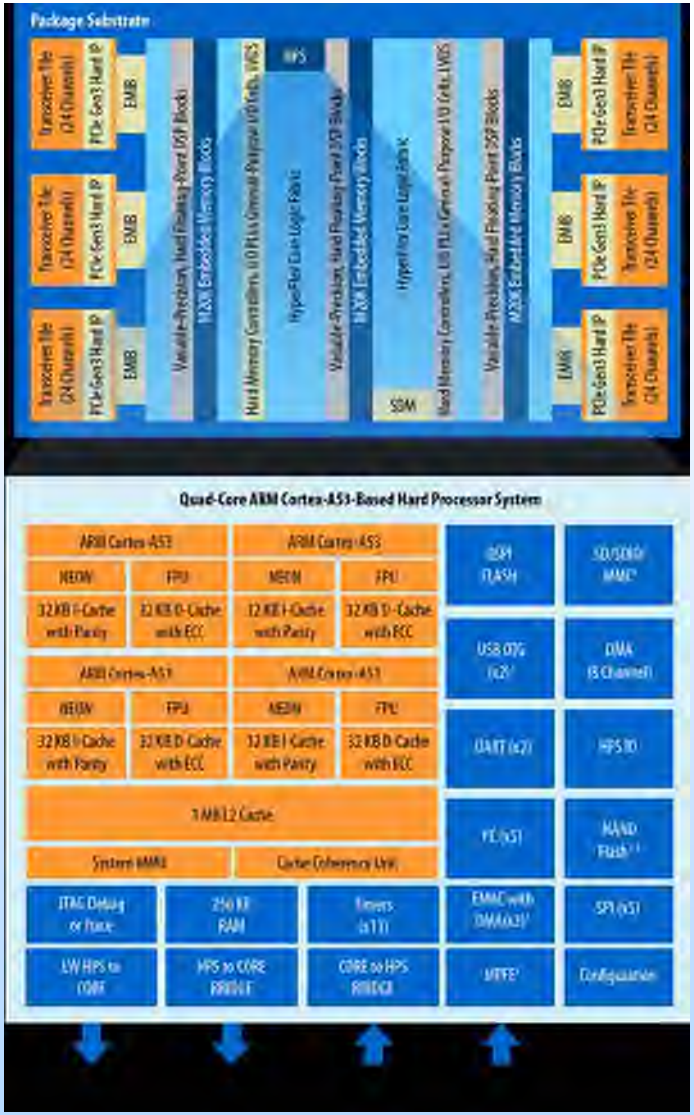
Radiation Testing ***Package Reliability Testing (CN)***

FY14 **FY15** **FY16** **FY17**

Next Generation “FPGAs”?



From Xilinx.com



From Altera.com

Advanced Processors

- collaborative with NSWC Crane, others

Next Generation Space Processor (NGSP)

- **Joint NASA-AFRL Program for RH multi-core processor**

TBD – (track status)

14nm CMOS Processors (w/Navy Crane)

- **Intel 14nm FinFET commercial**
  - **5th and 6th generation**
- **Samsung 14nm LP Snapdragon 820**

Radiation Testing

Radiation Testing

Freescale Processors

- **P2020 Communication Processor (w/Air Force)**
- **P5040 Network Processor**

Radiation Testing

Radiation Testing

RH Processor

- **BAE Systems RAD5510/5545**
  - **Leverages P5040 architecture**

Radiation Testing

Microcontrollers and Mobile Processors (Small Missions) -

includes Vorago ARM Cortex M0 in FY17

Radiation Testing

GPUs (Nvidia)

Radiation Testing

FY14 **FY15** **FY16** **FY17**

Commercial Memory Technology

- collaborative with NSWC Crane, others

Other

- MRAM (Avalanche STT, other)
- FeRAM

TBD – (track status/test when available)

Resistive

- CBRAM (Adesto)
- ReRAM (Panasonic)
- ReRAM (Tezzaron)
- TBD (HP Labs, others)

Radiation and Reliability Testing

45nm options

Radiation and Reliability Testing

Radiation and Reliability Testing

TBD – (track status)

DDR

- Intelligent Memory (robust cell twinning)
- 1xnm DDR3, DDR4, LP, new QDR

Radiation Testing

Radiation and Reliability Testing

Hybrid or wide I/O

- HMC, HBM, Wide I/O

TBD – (track status or test)

FLASH

- Samsung VNAND (gen 1, 2 – complete, gen 3 FY17)
- Micron 16nm planar
- Micron 3D
- SK Hynix 3D, other

Radiation and Reliability Testing

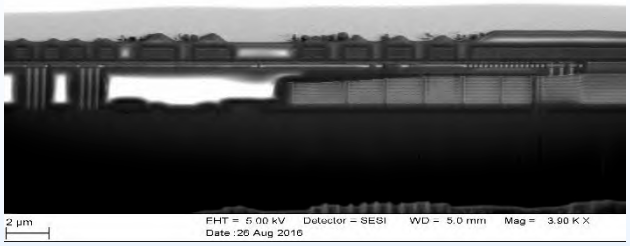
Radiation and Reliability Testing

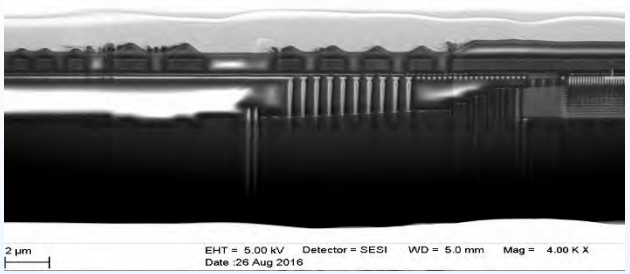
Radiation and Reliability Testing

Radiation and Reliability Testing

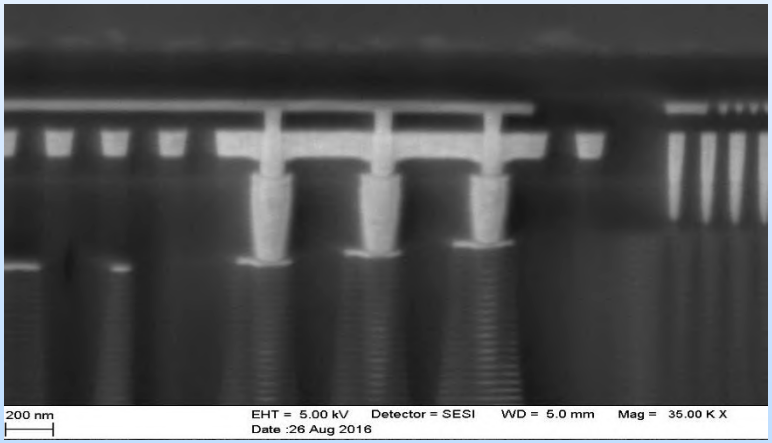
FY14 **FY15** **FY16** **FY17**

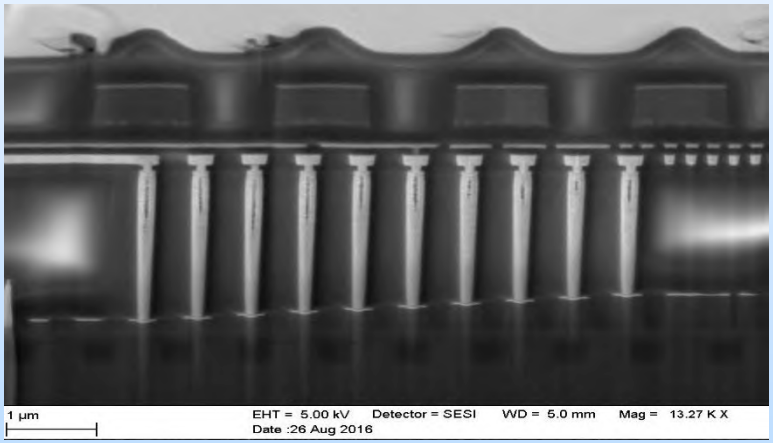
Hynix 3D 1X nm NAND FIB Cross-Section





Cross section showing FLASH array transition to periphery. Connections are identified for reference to higher magnification images in slides 10-11. Cross sections were taken along the Y-Axis





Higher magnification images of array connections 1 (left) and 2 (right)

NAND Flash provides non-volatility and extremely high memory density of interest to NASA flight projects.

This work is being performed collaboratively with NSWC Crane and coordinated with NASA STMD.

Alternate Grade Electronics: Automotive

- **NEPP has three goals for automotive electronics efforts**
  - **Determine exactly what:"automotive grade" does or does not entail.**
    - **Includes understanding:**
      - **Automotive Electronics Council (AEC) documents, and,**
      - **Manufacturer Production Part Approval Process (PPAP).**
  - **Perform "snapshot" screening and testing on representative automotive grade electronics.**
  - **Explore application of resilient automotive electronics system designs for space purposes.**

http://www.design-reuse.com/news_img/20141209_2.jpg

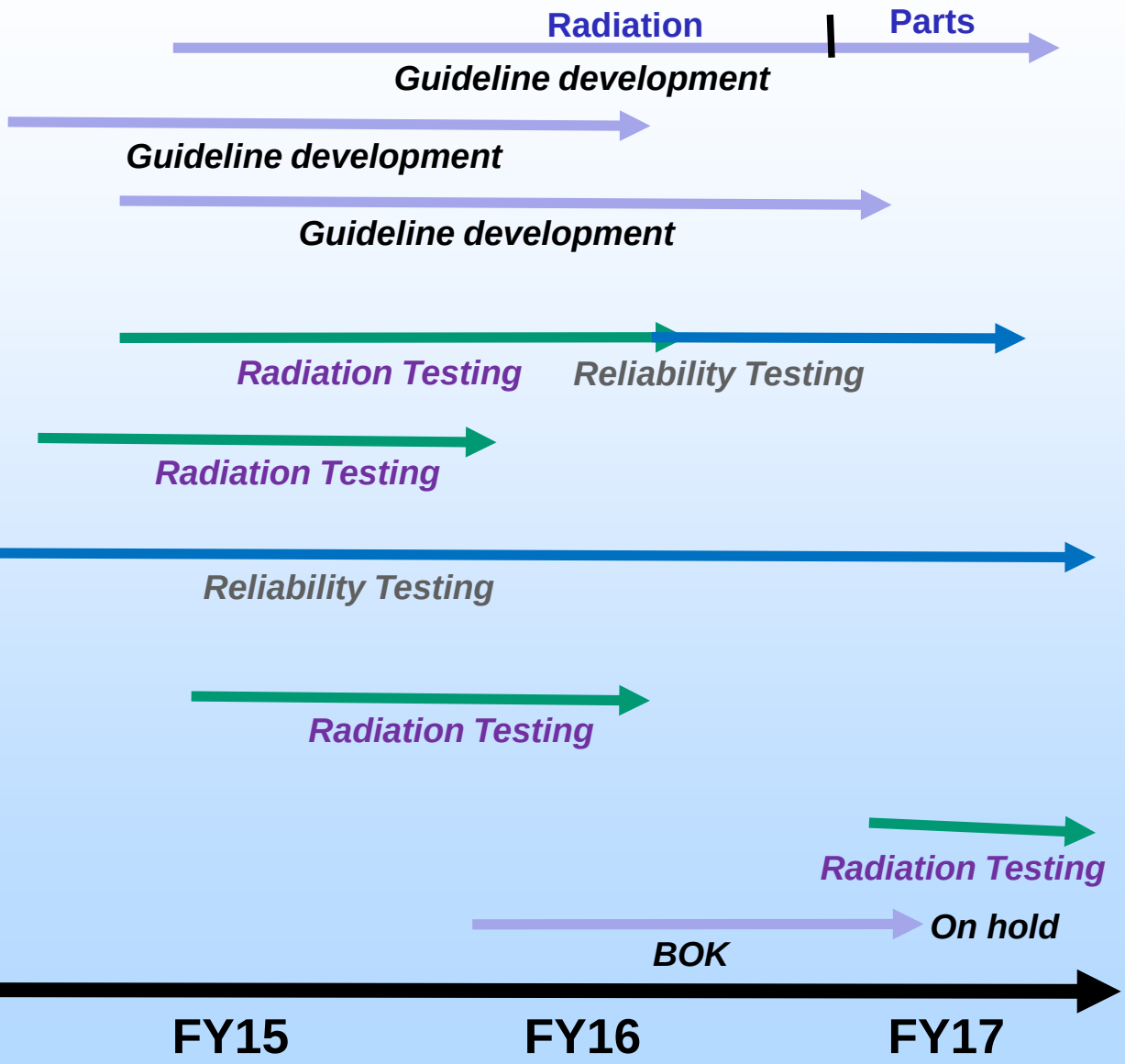
Small Missions/ Automotive

EEE Parts Guidelines
- Small mission best practices
- System on a chip (SOC) single event effects (SEE) guideline
- Board-level proton test guideline

Small Mission Commodities
- See commodities roadmaps for processors, memory, FPGAs, power
- CubeSat Star Tracker

Automotive grade electronics
- Multiple classes of electronics (passives, actives, ICs)
  - NASA and Navy Crane
- Freescale MPC56XX

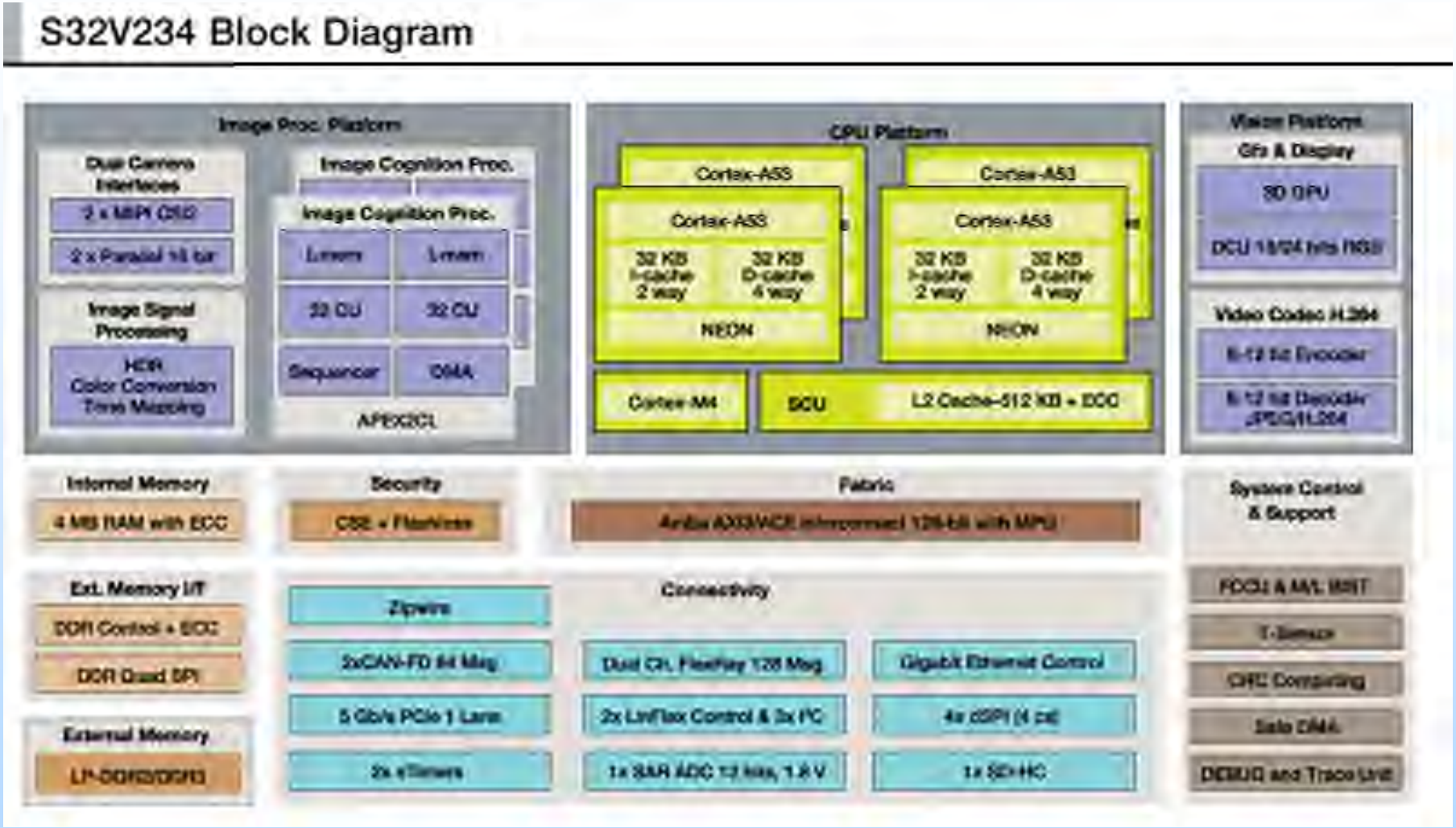
Alternate system tests
- Automotive resilience system tests
- Use of board-level testing for screening and qualification - BOK



NEPP and Small Missions/ Alternate "Assurance" Approaches

- **Sample Current Efforts**
  - **Radiation Hardness Assurance for Small Missions (Best Practices)**
  - **Root Cause Analysis and Success Tracking of CubeSats (Prof. Michael Swartwout/SLU) – we're looking for possible low hanging fruit for university-class CubeSats**
  - **Model-Based Missions Assurance (MBMA) for CubeSats:**
    - **1st task is a Goal Structuring Notation (GSN) exemplar of a CubeSat board – this is joint with the NASA Reliability and Maintainability (R&M) Program**
    - **FY17 follow-on adds Bayesian Methods**
  - **Board-level proton test guideline**
  - **Automotive grade EEE parts**
  - **CubeSat parts database – both kit manufacturers and usage within NASA**
    - **Have formed a small working group on sharing information**
  - **Multiple COTS evaluation tasks relevant to CubeSats**
- **Future considerations**
  - **COTS, COTS, COTS (and alternate grade electronics)**
  - **EEE Parts Best Practices for Small Missions**
  - **Board level testing for EEE parts assurance?**

Automotive - Advanced Driver Assistance Systems (ADAS) for *Space*?



From Freescale.com

Power and Widebandgap (WBG) Devices

Si MOSFETs – Rad Hardened

- Microsemi i2MOS
- Infineon superjunction
  100 V, 600 V (target)

Si Schottky Diodes and similar

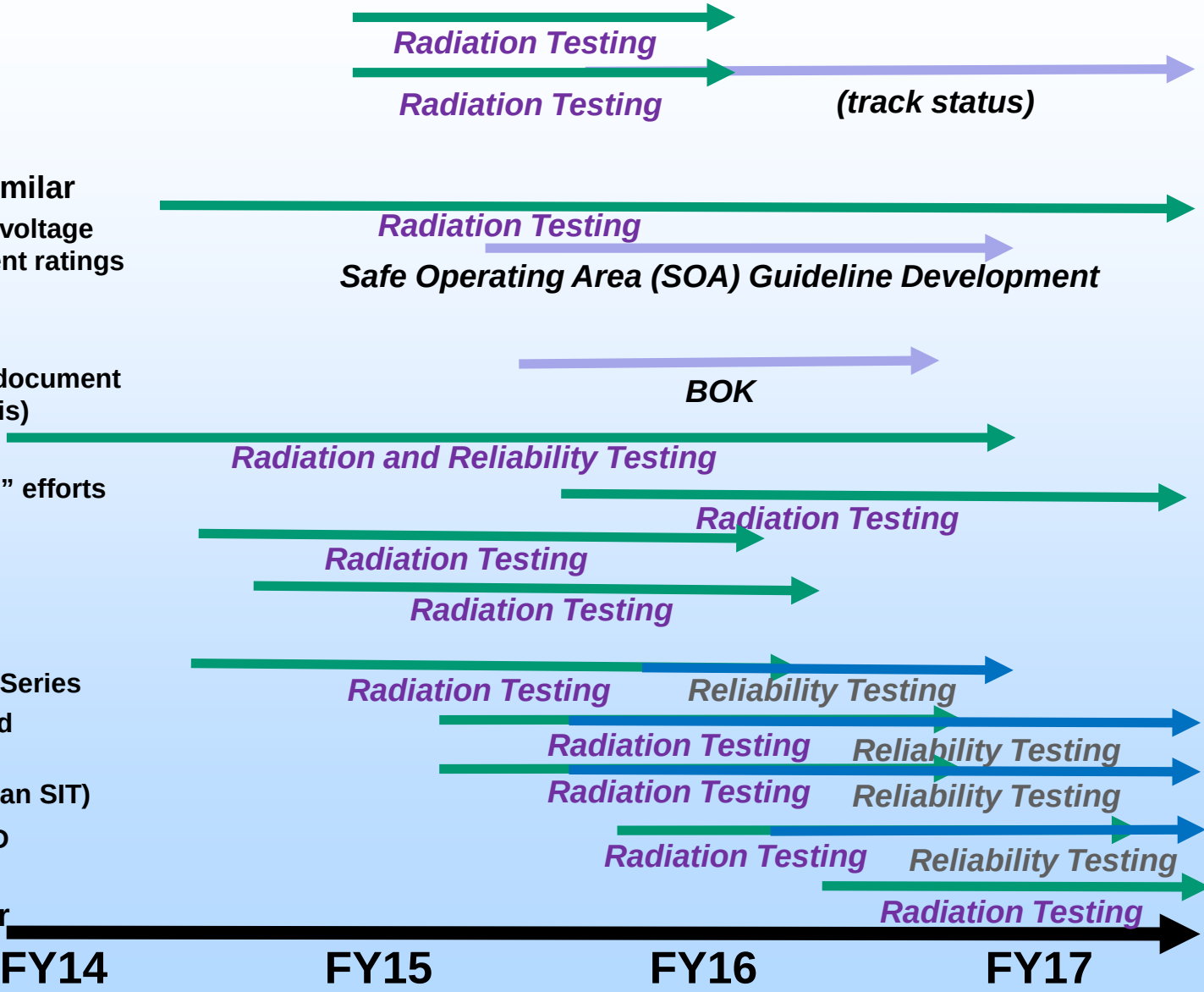
- Multiple vendors, reverse voltage ratings, and forward current ratings

SiC

- Body of Knowledge (BOK) document (knowledge and gap analysis)
- Cree Gen 1-3
- Collaboration w "hardening" efforts
- Baseline diodes
- Logic devices

GaN

- EPC 2012 (Gen3) and 8000 Series
- GaNSystems - GS61008 and GS66508 commercial
- Panasonic PGA26E19BA (Gan SIT)
- Thransphorm TPH3202PD (Cascode)
- Freebird Semiconductor



IC Packaging

High Density, Non-hermetic Column Grid Array (CGA)
- Xilinx CN/Kyocera Daisy Chain
- Microsemi Daisy Chain

HALT Methodology/Qualification
- HALT/HAST comparison
- Plastic BGA matrix

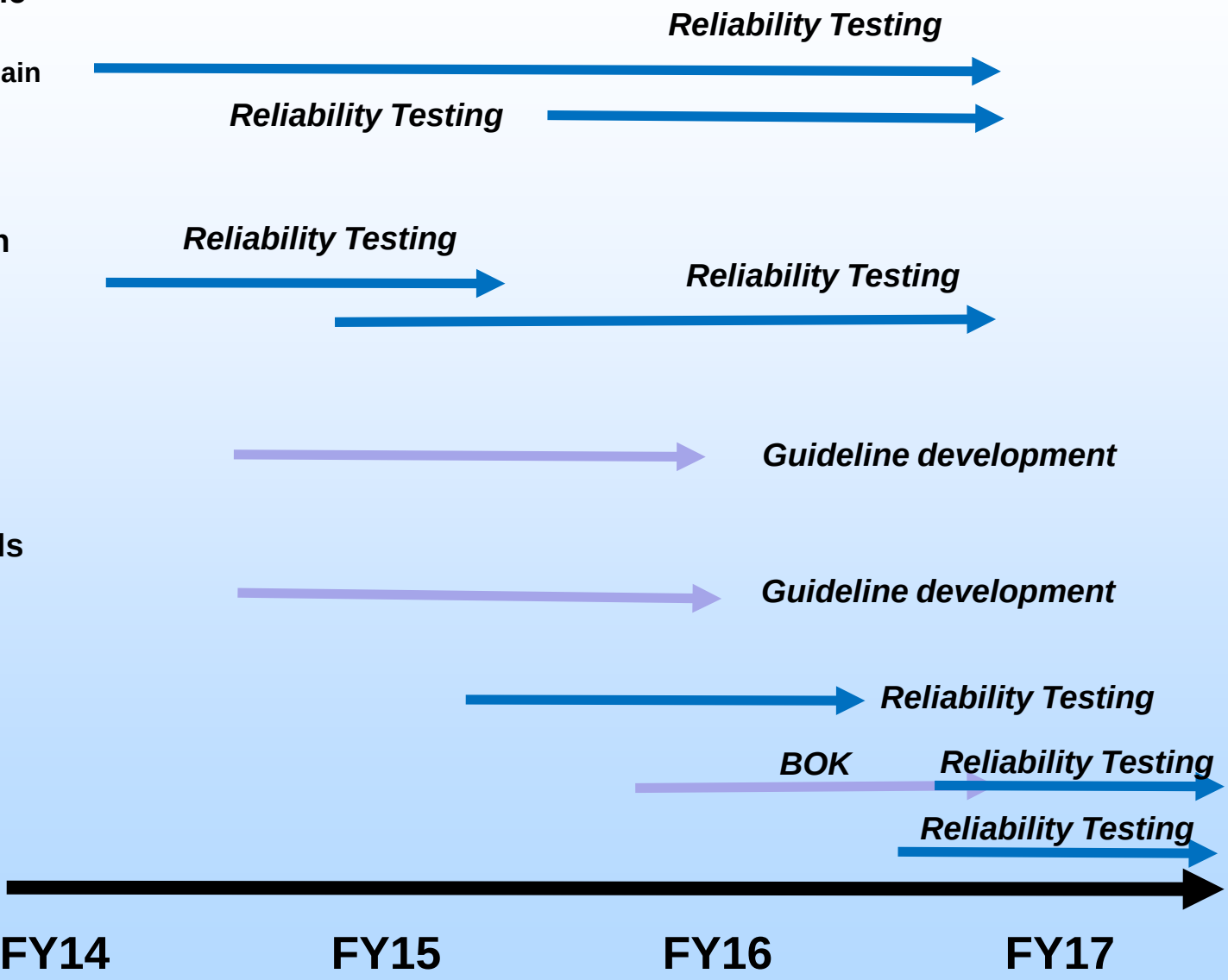
Area Array Column
- Selection guide

Thermal Interface Materials
- Selection guide

PBGA Thermal Cycle Evaluation

2.5/3D ICs

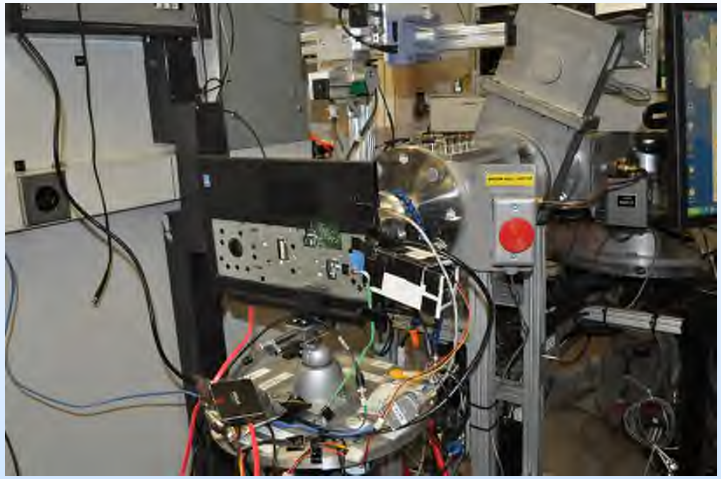
QFN Package Reliability



Proton Facilities Update – 200 MeV regime

- **Prime Proton Research Facilities**
  - **Massachusetts General Hospital (MGH) Francis H. Burr Proton Therapy Center**
    - **Provides 24 hours for 3 out 4 weekends a month**
    - **Highly used by industry and all Agencies**
      - **Over 80% booked already for CY17! Limited availability for NASA**
  - **Tri-University Meson Facility (TRIUMF) – Vancouver, CAN**
    - **Runs 4 cycles a year**
- **Proton Cancer Therapy Facilities Taking Customers**
  - **Loma Linda University Medical Center (LLUMC)**
    - **Weekend usage with limited available time beyond current load**
  - **SCRIPPS Proton Therapy Center**
    - **Some weekend access**
    - **Has 4 industry user contracts and not taking additional users**
  - **Hampton University Proton Therapy Institute (HUPTI)**
    - **Open for business (partial)**
    - **Evaluating options for additional time and capabilities (NEPP supporting)**
      - **Seeking individual user contract of ~100 hrs/year or more**
- **Proton Research Facilities – Proposals**
  - **Los Alamos Neutron Science Center (LANSCE)**
    - **Has 800 MeV proton source with white paper to modify for SEE test purposes (internal funding)**
    - ***Planned visit in October***
- **Proton Cancer Therapy Facilities – Pending Access**
  - **U MD Proton Therapy Center (Baltimore)**
    - **Expectation of completed medical commissioning by end of CY16 – shakeout test in CY17**
    - **Planning similar mode to SCRIPPS – limited number large hour users only (100 hours/year or more) – TBD total yearly hours**
  - **University of Florida Proton Health Therapy Institute (UFHPTI)**
    - **Completing medical commissioning**
    - **TBD yearly hours available to community but expect ~300 hours/year**
    - **Expect shakeout test in 1-2Q FY17**
  - **Case Western University Hospital Seidman Cancer Center**
    - **NASA GRC working a SAA with expected visit in fall**
    - **Small facility with expected limited hours (but great for GRC!)**
  - **Mayo Clinic**
    - **Two proton facilities (Rochester, MN and Phoenix, AZ)**
      - ***Meeting planned in Rochester in October***
      - **Research room built and have experience with government contracts**
  - **ProVision (Knoxville)**
    - **TBD – 2 rooms opening with TBD excess capacity in TBD timeframe in 2017**

NEPP Test Pictures



NEPP and NSWC Crane members participate in a test for simulation of effects from Galactic Cosmic Ray (GCR) environment at Texas A&M University's Cyclotron Institute on Intel processors.

Flash memory microcontroller tester, adaptable for most NAND flash devices on the market. Capabilities like this are often used by flight projects after NEPP development (and, of course, NEPP tests).

Summary and Comments

- **NEPP Roadmaps and Tasks are constantly evolving as technology and products become available.**
  - **Like all technology roadmaps, NEPP's is limited to funding and resource availability.**
    - **Many other efforts are not being shown today (60+ tasks total)**
    - **Note: CREME96 website operations is funded by NEPP (but not improvements nor CRÈME MC)**
  - **Partnering is the key:**
    - **Government,**
    - **Industry, and,**
    - **University.**
- **We look forward to further opportunities to partner and hope to see you at our workshop June 19-22, 2017.**

https://nepp.nasa.gov